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CRITICAL ANALYSIS OF INTERNAL STABILITY METHODS FOR ANALYSIS OF REINFORCED SOIL WALLS

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ABSTRACT

Due to growing restrictions on right-of-way, wetlands, or other space-limiting conditions, the demand for design and construction of Mechanically Stabilized Earth (MSE) Walls are increasing worldwide, in general and India in particular. There are two stages of analysis of reinforced earth walls, namely external stability and internal stability. Internal Stability deals with the tensile and pullout failure of the reinforcement. Different Codes/ Standards are available for analysis of reinforced earth walls. A study was undertaken to compare the approaches in these Codes. Therefore, this study emphasises on quantification and comparison of metallic reinforcements by analysis using Coherent Gravity Method as per British Standard(BS-8006) and Federal Highway Administration (FHWA-(NHI-10-024)). The results are compared and reported in this paper.

KEYWORDS: Coherent Gravity Method, Height of Wall, Quantity of Reinforcement, Reinforced Soil Walls, Standards, Spacing of Reinforcement

INTRODUCTION

Reinforced Soil Structures (RS) or Mechanically Stabilized Earth (MSE) Structures are one of the most commonly used earth retaining Structures. The design and construction of Reinforced Soil Structures has transformed the earth retention options available. Due to growing restrictions on right-of-way, wetlands, or other space-limiting conditions, the demand for design and construction of MSE Walls are increasing worldwide. A RS/MSE wall is inexpensive and is fairly easy and fast to construct since it is easy to lay out alternate layers of soil and reinforcement or perform compaction. Tensile reinforcement is placed between layers of soil to prevent the soil from failing. The reinforcement strengthens the soil, making it possible to build structures higher and stronger than structures with soil-alone. The interaction between the reinforcement and the soil as a unit gives the mass greater strength than unreinforced soil mass. These structures serve as embankments, wing walls, slope protection, steep slopes and other places where a change in grade is required. There are three commonly adopted Standards or Codes for the analysis and design of reinforced earth retaining structures. This paper attempts to critically analyse the differences in the design approaches between two codes viz. British Standard 8006-1995 and FHWA Volume I, Nov 2009. Based on the comparison of the results obtained from the two approaches, conclusions have been drawn on which approach would be economical for a particular case where the variables are the wall height and the vertical spacing of the reinforcements.

DIFFERENT STANDARDS FOR REINFORCED EARTH WALLS

The three basic Standards followed in India for the analysis and design of Mechanically Stabilized Earth Walls (MSEW) are:

- BS 8006 (1995), Code of Practice for Strengthened Reinforced Soils and Other Fills. British Standardization Institute;, Milton Keynes UK.
- Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – FHWA Volume I, Nov 2009 (NHI-10-024)
- State of the Art: Reinforced Soil Structures Applicable to Road Design and Construction (IRC-Special Report-16)

In the above codes the design approach is to check the several possible failure modes in reinforced soil walls as in the case of any typical geotechnical design problem. These failure modes are checked in the design of reinforced soil structure for both external and internal stability. External stability checks assumes that the failure surface lies completely outside the reinforced soil mass. Internal stability checks have to cover all possible failures for which the assumed sliding surface intersects the reinforcement. An adequate factor of safety against rupture and pullout of the reinforcing elements has to be proven. There are fundamentally two approaches used by these codes for the analysis of a reinforced earth wall. These are the 'coherent gravity method' and the 'tie back method'. This paper restricts itself to the analysis by the coherent gravity method using two codes.

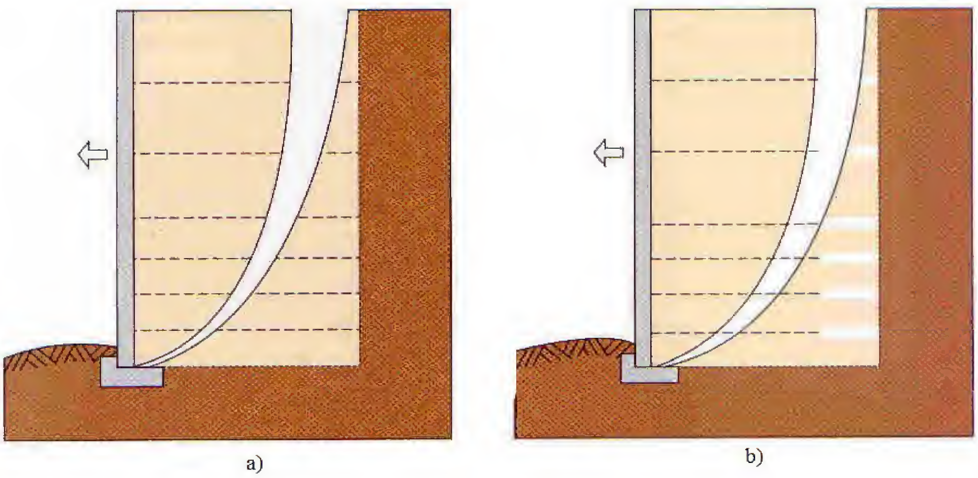

Figure 1: a) Tension Failure b) Pullout Failure

OBJECTIVE AND SCOPE OF THE ANALYSIS

The objective was to carry out a comparative study on how the two different Standards namely the British Standard (BS) and FHWA (2009)differs in explaining the internal stability method, Coherent Gravity for Mechanically Stabilised Earth Walls (MSEW) and thereby calculating the Quantity of Reinforcement which varies across the Standards. The reinforcement considered was metallic strips. Designs were carried out for four wall heights namely 9m, 7m, 5m and 3m respectively using the Coherent Gravity Method using the two Standards. The vertical spacing of the reinforcements was considered as either 0.375m and 0.75m from practical considerations and the quantity of reinforcements for unit area of the wall was computed. This study helps a designer to easily calculate the quantity of reinforcements calculated as per each of the above Standard and also compare them. The percentage variation in each of the above Standard was also calculated. The backfill considered was granular with the following assumptions.

Table 1

Sl No	Parameter	Value
1	Angle of internal friction of wall fill	32^{0}
2	Density of the wall fill (ϒw)	2000 kg/m^3
3	Uniformity Coefficient (Cu)	4

LITERATURE REVIEW

Coherent Gravity method was originally developed by Juran and Schlosser (1978)[1], Schlosser(1978)[2], and Schlosser and Segrestin (1979)[3] to estimate reinforcement stresses for steel strip reinforced precast panel-faced MSE walls. They utilized the concepts developed by Meyerhof (1953)[4] to determine the vertical pressure beneath an eccentrically loaded concrete footing. Meyerhof's approach was applied to the reinforced soil mass at each reinforcement level and the wall base by assuming that the reinforced soil mass behaves as a rigid body, allowing the lateral load acting at the back of the reinforced soil zone to increase the vertical stress by overturning the moment to greater than ϒz. The lateral stress carried by the reinforcement was determined by applying to the vertical stress a lateral earth pressure coefficient calculated from the soil friction angle. The stress carried by each reinforcement was assumed to be equal to the lateral soil stress over the tributary area for each reinforcement. This was based on the assumption that the reinforcement fully supports the near vertical face of the wall, that it is, in essence, a tieback.

This lateral earth pressure coefficient was assumed to be Ko at the top of the wall, decreasing to Ka at a depth of 6 m below the wall top. Ko conditions were assumed at the wall top because of potential locked-in-compaction stresses, as well as the presence of lateral restraint from the relatively stiff reinforcement material, which was assumed to prevent active stress conditions from developing. With depth below the wall top, the method assumes that these locked-in-compaction stresses are overcome by the overburden stress, and deformations become great enough to mobilize active stress conditions. These assumptions were verified at the time, at least observationally, on the basis of measurements from full-scale walls. All walls were steel strip reinforced with precast concrete facing panels (Schlosser, 1978)[1]. The data in Figure 1 are presented as a Kr/Ka ratio, and from this, as well as the theoretical concepts mentioned above, Schlosser (1978) [1] concluded that Ko and Ka could be used directly as lateral earth pressure coefficients for the design of MSE walls. Note, however, that the equation typically used to calculate Ko was derived for normally consolidated soils, and compaction would tend to make the soil behave as if it were over consolidated.

The design methodology is summarized in equations 1 through 6, and figures 3 and 4. Other MSE wall systems such as bar mat reinforced walls (Neely, 1993)[5] and geogrid reinforced walls (from 1983 to 1987) (Netlon, 1983)[6] adopted this design methodology. Welded wire MSE wall systems initially used a pseudo tieback-wedge method (Mitchell and Villet, 1987[7]; Anderson et al., 1987) [8]. Welded wire MSE wall systems typically used a higher lateral stress than the Coherent Gravity model based on full-scale instrumented structures (Mitchell and Villet, 1987)[7]. However, once AASHTO adopted the Coherent Gravity model without distinction for reinforcement type, the welded wire wall systems shifted to that methodology.

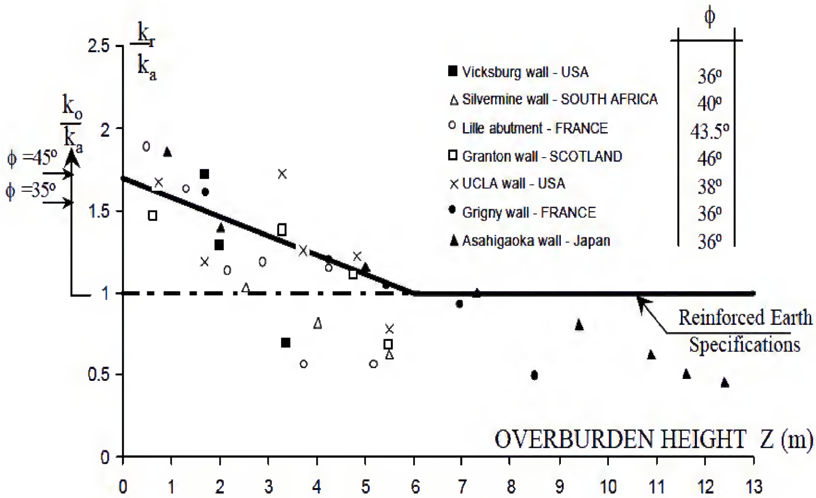

Figure 1: Variation of Kr/Ka for Steel Strip Reinforced Walls (Adopted from Schlosser, 1978)

$$T_{\max} = S_v R_c (\sigma_v K_r) \tag{1}$$

Where Tmax=Peak reinforcement load at each reinforcement level

Sv =Vertical spacing of the reinforcement

Rc=reinforcement coverage ratio

σv = vertical stress at each reinforcement level as determined from equations 2 and 3

Kr=lateral stress ratio which varies from K_o to K_a based on the reinforcement zone soil properties as shown in Figure 2.1. (Ka is determined by assuming a horizontal back slope and no wall friction in all cases).

$$\sigma_v = \frac{V_1 + V_2 + F_T \sin\beta}{L - 2e} \tag{2}$$

Where σv = vertical stress at each reinforcement level

V_1=Weight of the reinforced soil zone

V2=Weight of the soil mass above the reinforced zone contained in the horizontal back slope

β = Nominal slope of backfill behind wall (deg)

F_T=Force due to earth pressure caused by retained backfill inclined at an angle β with the horizontal

e=eccentricity of the resultant load

$$e = \frac{F_T(\cos\beta)h/3 - F_T(\sin\beta)L/2 - V_2(L/6)}{V_1 + V_2 + F_T \sin\beta} \tag{3}$$

Where h= Total height of the wall including the surcharge as shown in Figure 2.2

L=Length of the reinforced soil zone

FT, β, V1, V2 are explained in (2)

$$K_o = 1 - \sin\phi \tag{4}$$

Where Ko=Coefficient of earth pressure at rest

$$K_a = Tan^2(45 - \phi/2) \tag{5}$$

ϕ=Peak soil friction angle of the reinforced backfill

Where Ka= Coefficient of active earth pressure

$$H_1 = H + \frac{Tan\beta \times 0.3H}{1 - 0.3Tan\beta} \tag{6}$$

Where H1= Depth of the active zone considered from top as shown in Figure 2.3

H= Height of the reinforced soil zone

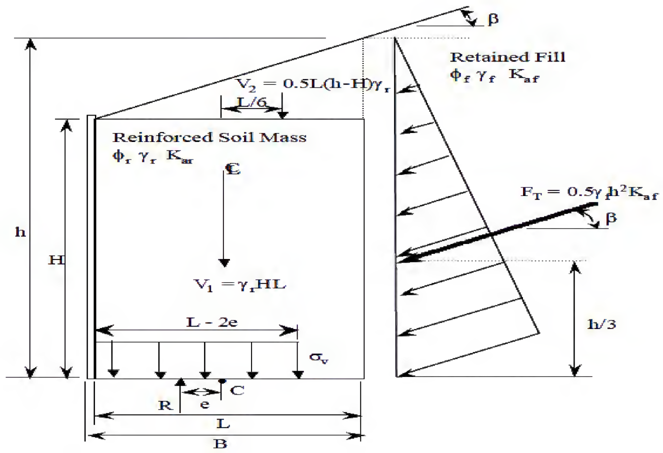

Figure 2: Forces and Stresses for Calculating Meyerhof Vertical Stress Distribution in MSE Walls (Adopted from AASHTO, 1999)

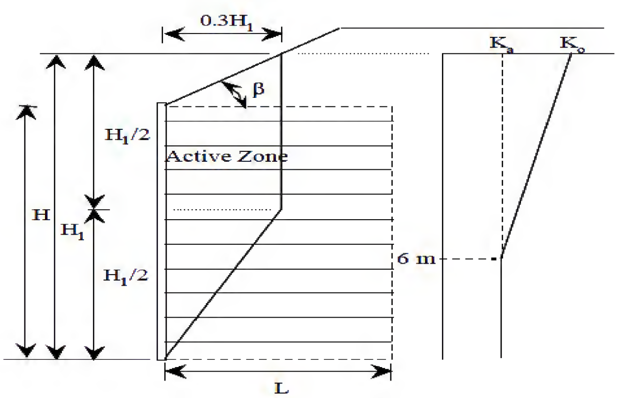

Figure 3: Determination of Lateral Earth Pressure Coefficients Failure Plane Location for Internal Stability Design Using the Coherent Gravity Method (Adopted from AASHTO, 1996)

ANALYSIS

Coherent Gravity method of analysis described as per British Standard(1995) and FHWA-Nov 2009 (Publication No: FHWA-NHI-10-024, FHWA-NHI-10-025, FHWA-NHI-09-087) is done separately. The analysis is carried out for wall heights of 9m, 7m, 5m and 3m. A founding length of 1.5m is considered in each of the above cases by which the total height of the walls becomes 10.5m, 8.5m, 6.5m and 4.5m respectively. An additional 1m height of surcharge is also considered for the above cases. The analyses were carried out by using the formulae as per the two codes in an Excel Worksheet.

In actual construction, the vertical spacing of reinforcement is kept as 0.375m at the bottom and it is increased as we go up when the factor of safety increases. In the design which is shown in this paper, vertical spacing is uniformly kept as 0.375m in Cases 1,2,5,6,9,10,13 and 14 and 0.75m in Cases 3,4, 7,8,11,12,15 and 16. The horizontal spacing is taken uniformly as 0.75m in all the cases. The length of the reinforcement considered in each of the cases were the ones which pass the external stability check and the minimum length of reinforcement prescribed by each Standard (0.7H or 3m whichever is greater).Based on this, the quantity of reinforcement is evaluated by the two codal procedures ie, BS and FHWA for a factor of safety close to one. The same has been considered for all the four wall heights.

The various cases are tabulated below in Table 1

Table 1: Various Parameters Assumed for Analysis for Comparison between BS and FHWA Methods of Analysis for Different Wall Heights and Length of Reinforcements

Name of the Standard	Case	Vertical Spacing(m)	Horizontal Spacing (m)	Wall Height(m)	Length of Reinforcement (m)
BS	1	0.375	0.75	9.0	9.5
FHWA		0.375	0.75	9.0	9.5
BS	2	0.375	0.75	9.0	8.1
FHWA		0.375	0.75	9.0	8.1
BS	3	0.75	0.75	9.0	9.5
FHWA		0.75	0.75	9.0	9.5
BS	4	0.75	0.75	9.0	8.1
FHWA		0.75	0.75	9.0	8.1
BS	5	0.375	0.75	7.0	7.6
FHWA		0.375	0.75	7.0	7.6
BS	6	0.375	0.75	7.0	6.7
FHWA		0.375	0.75	7.0	6.7
BS	7	0.75	0.75	7.0	7.6
FHWA		0.75	0.75	7.0	7.6
BS	8	0.75	0.75	7.0	6.7
FHWA		0.75	0.75	7.0	6.7
BS	9	0.375	0.75	5.0	5.8
FHWA		0.375	0.75	5.0	5.8
BS	10	0.375	0.75	5.0	5.3
FHWA		0.375	0.75	5.0	5.3
BS	11	0.75	0.75	5.0	5.8
FHWA		0.75	0.75	5.0	5.8
BS	12	0.75	0.75	5.0	5.3
FHWA		0.75	0.75	5.0	5.3
BS	13	0.375	0.75	3.0	4.2
FHWA		0.375	0.75	3.0	4.2
BS	14	0.375	0.75	3.0	3.9

FHWA		0.375	0.75	3.0	3.9
BS	15	0.75	0.75	3.0	4.2
FHWA		0.75	0.75	3.0	4.2
BS	16	0.75	0.75	3.0	3.9
FHWA		0.75	0.75	3.0	3.9

RESULTS OF THE ANALYSES

For the sixteen(16) combinations tabulated above detailed analysis was carried out by running a developed programme. The results of the analyses and findings are presented here in the form of graphs and comparative statements. There are two vertical spacing of the reinforcement considered viz. 0.375m and 0.75m. The results are presented for the above 16 cases separately for the two vertical spacing of the reinforcement. The horizontal spacing is maintained at 0.75m in all the cases.

Table 2: Quantity of Reinforcement for BS 8006(1995) and FHWA Standards for Vertical Spacing = 0.375m

Sl No	Height of Wall (m)	Length of Reinforcement (m)	Name of the Standard	Vertical Spacing(m)	Horizontal Spacing(m)	Quantity of Steel (kg/sqm)
1	9.00	9.5	BS	0.375	0.75	**49.12**
2			FHWA	0.375	0.75	**69.03**
3	7.00	7.6	BS	0.375	0.75	**39.68**
4			FHWA	0.375	0.75	**55.89**
5	5.00	5.8	BS	0.375	0.75	**30.95**
6			FHWA	0.375	0.75	**47.32**
7	3.00	4.2	BS	0.375	0.75	**21.32**
8			FHWA	0.375	0.75	**44.41**

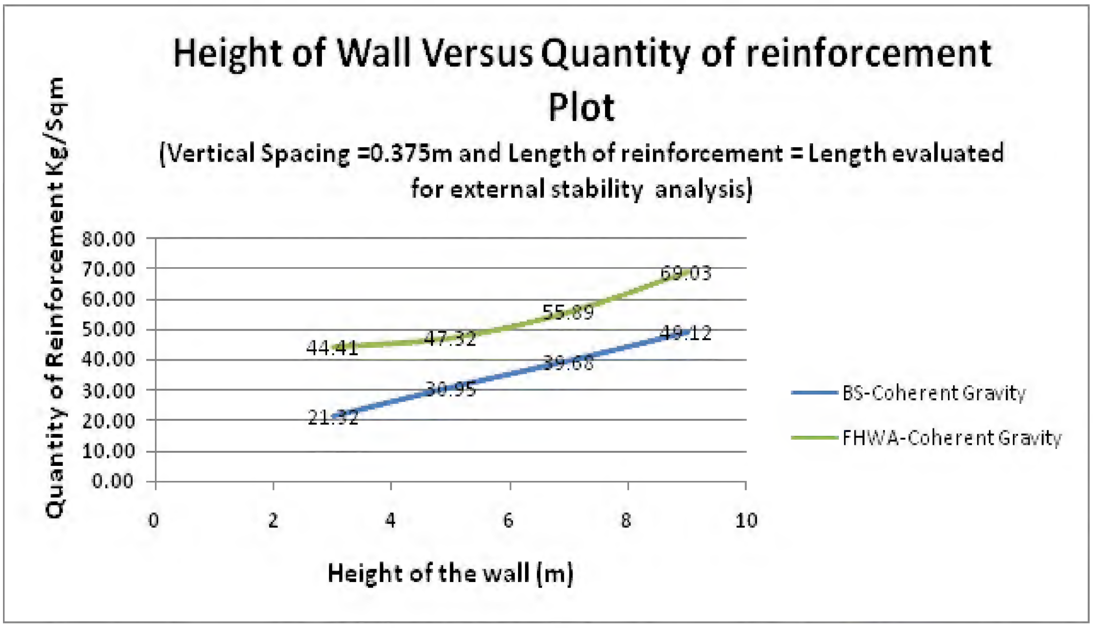

Figure 4: Variation of Quantity of Reinforcement with Height of the Wall for Different Standards for a Vertical Spacing of 0.375m and Length of Reinforcement=Length Evaluated for External Stability Analysis

Table 3: Percentage Variation of Quantity of Reinforcement in FHWA Keeping BS as Base Datum for all Wall Heights for a Vertical Spacing of 0.375m and Length of Reinforcement Evaluated for External stability Analysis

Height of Wall (m)	Length of Reinforcement (m)	Vertical Spacing(m)	Horizontal Spacing(m)	Percentage Variation in the Quantity of Steel keeping BS as Base Datum %
9.00	9.5	0.375	0.75	+40.53
7.00	7.6	0.375	0.75	+40.85
5.00	5.8	0.375	0.75	+52.89
3.00	4.2	0.375	0.75	+108.3

Table 4: Quantity of Reinforcement for Different Standards for Vertical Spacing=0.375m and Length of Reinforcement=0.7H

Sl No	Height of Wall (m)	Length of Reinforcement (m)	Name of the Standard	Vertical Spacing(m)	Horizontal Spacing(m)	Quantity of Steel (kg/sqm)
1	9.00	8.1	BS	0.375	0.75	44.79
2			FHWA	0.375	0.75	61.08
3	7.00	6.7	BS	0.375	0.75	36.93
4			FHWA	0.375	0.75	53.65
5	5.00	5.3	BS	0.375	0.75	29.44
6			FHWA	0.375	0.75	48.67
7	3.00	3.9	BS	0.375	0.75	20.57
8			FHWA	0.375	0.75	45.96

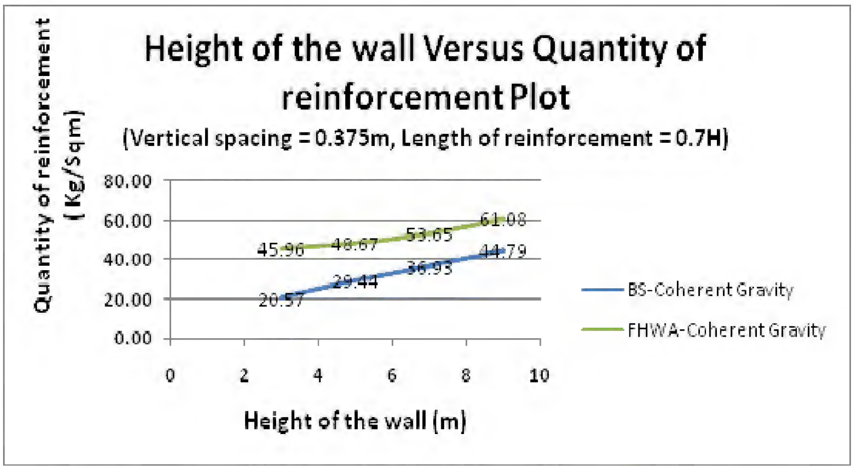

Figure 5: Variation of Quantity of Reinforcement with Height of the Wall for Different Standards for a Vertical Spacing of 0.375m and Length of Reinforcement=0.7H

Table 5: Percentage Variation of Quantity of Reinforcement in FHWA Keeping BS as Base Datum for all Wall Heights for a Vertical Spacing of 0.375m and Length of Reinforcement=0.7H

Height of Wall (m)	Length of Reinforcement (m)	Vertical Spacing(m)	Horizontal Spacing(m)	Percentage Variation in the Quantity of Steel Keeping BS as Base Datum %
9.00	8.1	0.375	0.75	+36.36
7.00	6.7	0.375	0.75	+45.27
5.00	5.3	0.375	0.75	+65.32
3.00	3.9	0.375	0.75	+123.43

Table 6: Quantity of Reinforcement for Different Standards for Vertical Spacing=0.75m and Length of Reinforcement=Length of Reinforcement Evaluated for External Stability Analysis

Sl No	Height of Wall (m)	Length of Reinforcement (m)	Name of the Standard	Vertical Spacing(m)	Horizontal Spacing(m)	Quantity of Steel (kg/sqm)
1	9.00	9.5	BS	0.75	0.75	45.56
2			FHWA	0.75	0.75	61.58
3	7.00	7.6	BS	0.75	0.75	35.98
4			FHWA	0.75	0.75	51.26
5	5.00	5.8	BS	0.75	0.75	28.66
6			FHWA	0.75	0.75	46.66
7	3.00	4.2	BS	0.75	0.75	21.81
8			FHWA	0.75	0.75	44.55

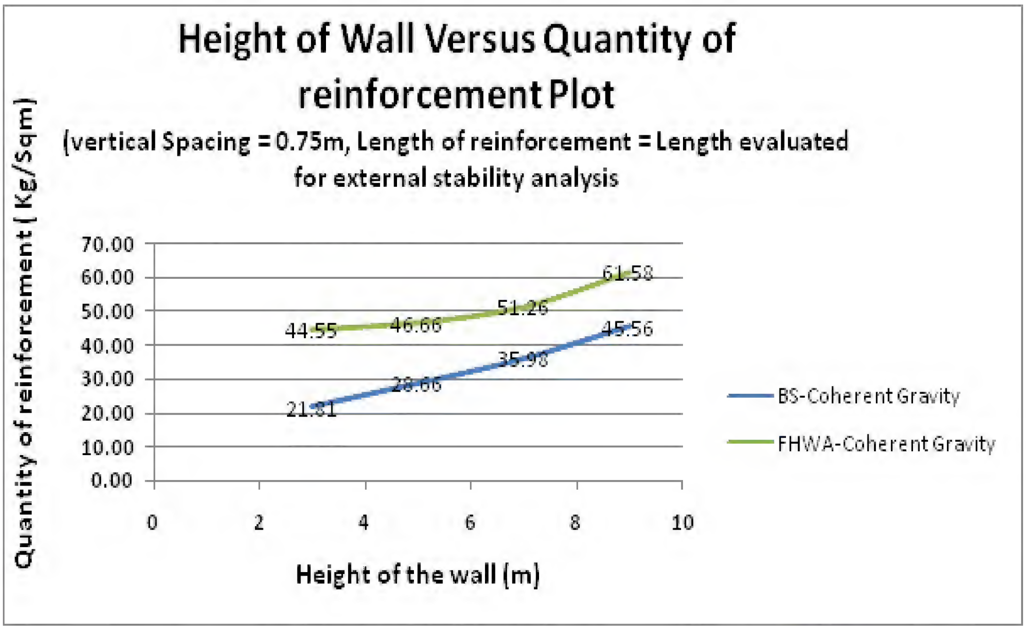

Figure 6: Variation of Quantity of Reinforcement with Height of the Wall for Different Standards for a Vertical Spacing of 0.75m and Length of Reinforcement= Length Evaluated for External Stability Analysis

Table 7: Percentage Variation of Quantity of Reinforcement in FHWA Keeping BS as Base Datum for all Wall Heights for a Vertical Spacing of 0.75m and Length of Reinforcement=Length Evaluated for External Stability Analysis

Height of Wall (m)	Length of Reinforcement (m)	Vertical Spacing (m)	Horizontal Spacing (m)	Percentage Variation in the Quantity of Steel Keeping BS as Base Datum %
9.00	9.5	0.75	0.75	+35.16
7.00	7.6	0.75	0.75	+42.46
5.00	5.8	0.75	0.75	+62.81
3.00	4.2	0.75	0.75	+104.26

Table 8: Quantity of Reinforcement for Different Standards for Vertical Spacing=0.75m and Length of Reinforcement=0.7H

Sl No	Height of Wall (m)	Length of Reinforcement (m)	Name of the Standard	Vertical Spacing (m)	Horizontal Spacing (m)	Quantity of Steel (kg/sqm)
1	9.00	8.1	BS	0.75	0.75	41.96
2			FHWA	0.75	0.75	56.55
3	7.00	6.7	BS	0.75	0.75	36.88
4			FHWA	0.75	0.75	52.08
5	5.00	5.3	BS	0.75	0.75	27.47
6			FHWA	0.75	0.75	48.41
7	3.00	3.9	BS	0.75	0.75	22.62
8			FHWA	0.75	0.75	46.14

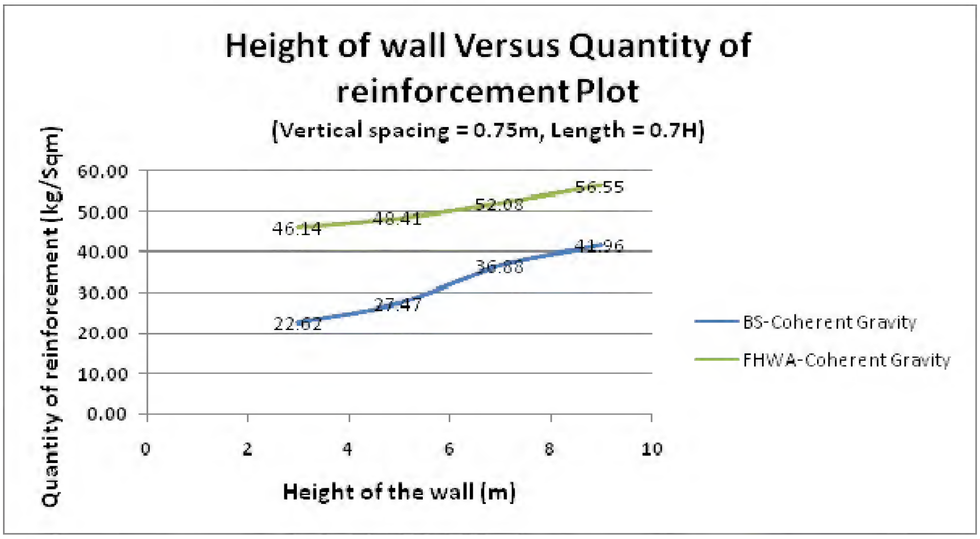

Figure 7: Variation of Quantity of Reinforcement with Height of the Wall for Different Standards for a Vertical Spacing of 0.75m and Length of Reinforcement=0.7H

Table 9: Percentage Variation of Quantity of Reinforcement Keeping BS as Base Datum for all Wall Heights for a Vertical Spacing of 0.75m and Length of Reinforcement=0.7H

Height of Wall (m)	Length of Reinforcement (m)	Vertical Spacing(m)	Horizontal Spacing(m)	Percentage Variation in the Quantity of Steel keeping BS as base datum %
9.00	8.1	0.75	0.75	+34.77
7.00	6.7	0.75	0.75	+41.21
5.00	5.3	0.75	0.75	+76.45
3.00	3.9	0.75	0.75	+103.97

FINDINGS OF THE STUDY

Based on the results that have emerged out of the study, the following inferences are drawn:

- Figure 5 depicts the variation of quantity of reinforcement with height of the wall for the two different standards for a vertical spacing of 0.375m and Length of Reinforcement (evaluated as per external stability). It has been observed that among the two standards, FHWA gives the highest quantity of reinforcement for this particular

combination. Based on this data the percentage variation of the quantities of reinforcement keeping the BS – 8006(1995) as the base datum has been computed and is shown in Table 3.

- Figure 6 depicts the variation of quantity of reinforcement with height of the wall for the two different standards for a vertical spacing of 0.375m and Length of Reinforcement kept as 0.7H. It has been observed that among the two standards, FHWA gives the highest quantity of reinforcement for this particular combination. Based on this data the percentage variation of the quantities of reinforcement keeping the BS – 8006(1995) as the base datum has been computed and is shown in Table 6.
- Figure 7 depicts the variation of quantity of reinforcement with height of the wall for the two different standards for a vertical spacing of 0.75m and Length of Reinforcement (evaluated as per external stability) . It has been observed that among the two standards, FHWA gives the highest quantity of reinforcement for this particular combination. Based on this data the percentage variation of the quantities of reinforcement keeping the BS – 8006(1995) as the base datum has been computed and is shown in Table 7.
- Figure 8 depicts the variation of quantity of reinforcement with height of the wall for the two different standards for a vertical spacing of 0.75m and Length of Reinforcement kept as 0.7H. It has been observed that among the two standards, FHWA gives the highest quantity of reinforcement for this particular combination. Based on this data the percentage variation of the quantities of reinforcement keeping the BS – 8006(1995) as the base datum has been computed and is shown in Table 9.

CONCLUSIONS

The above analyses compare the results of adopting two different codes for evaluating the quantities of reinforcement for a reinforced soil wall. The designer often has to make the choice on which code to adopt. The final consideration should be to evolve a most economical design that is optimal. Once the results based on one code is available, the corresponding value based on other code can be evaluated without performing the complete set of calculations, based on the findings of the study. The study will in particular help a reinforced earth wall designer in the following areas:

- From the above work, a designer of Reinforced Earth Wall can easily find out the quantity of reinforcements as per British Standard and Federal Highway Administration (FHWA) for wall heights namely, 3m, 5m, 7m and 9m.
- Quantity of reinforcement for any intermediate wall height for the respective Standards.
- The percentage variation in the quantity of reinforcements in FHWA keeping British Standard as datum is available in the Tables. This helps a designer to easily calculate the reinforcements in FHWA even if design is done according to British Standard only.

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